Erosion Control, Vegetative

Seth M. Dabney
United States Department of Agriculture (USDA), Oxford, Mississippi, U.S.A.

INTRODUCTION

Vegetation controls erosion by dissipating the erosive forces of rainfall and runoff (erosivity) and by reducing the susceptibility of soil to erosion (erodibility). Vegetation alters the partitioning of rainfall between infiltration, surface storage, and surface runoff. Erosivity is reduced because rainfall kinetic energy is absorbed, runoff volume is reduced due to increased infiltration, and runoff velocity is slowed through increased surface detention and reduced development of areas of concentrated flow. Vegetation reduces soil erodibility by increasing soil aggregation, binding aggregates together with roots, and lowering soil matric potential. Vegetation may cover the entire soil surface, as with crops, cover crops, or forests; or it may be limited to specific critical areas, as with various types of conservation buffers. This chapter reviews the mechanisms and processes by which vegetation reduces soil erosion by water, with emphasis on vegetative buffers. Crop residue effects are considered in another entry.

GENERAL MECHANISMS

Slower Runoff

Theoretically, if runoff occurs uniformly over a plane, its depth increases in a predictable manner as slope length increases. In practice, the development of concentrated flow areas of high velocity limits the depth of sheet flows. By slowing runoff, vegetation can reduce or delay the development of rills and associated concentrated-flow erosion. Vegetation may increase runoff depth 10-fold compared to an equivalent discharge over a smooth surface or fivefold deeper than rainfall-impacted flow over a natural bare soil surface.[1] By increasing water depth fivefold, average velocity, V, is reduced fivefold. Since erosivity of runoff is proportional to V^2 and its sediment transport capacity is proportional to V^5, (see Ref. [2]) vegetation reduces concentrated-flow erosion.

The retardation of surface runoff is a critical aspect of the functioning of conservation buffers. Fig. 1 shows the situation where sediment-laden runoff encounters a vegetated buffer. Because of the additional hydraulic resistance of stems and leaves, flow depth within the buffer, D_2, is greater than upslope of the buffer's influence, D_0. The depth at the upslope edge of the buffer, D_1, however, is greater even than that within the buffer (D_2) because of: 1) enhanced vegetation growth at the buffer margin; 2) compression of stems into a denser barrier; and 3) loading of the buffer edge with trapped residues and thatch. In many studies, more than half of the sediment trapped by vegetated buffers is deposited in the ponded area upslope of the buffer. Where the ponded area is deep and slow-flowing, transport capacity is negligible and the water surface approaches horizontal. In these circumstances, the fraction of particles with fall velocity V_{si} that will be trapped (T_i) is given by Ref. [3]:

$$T_i = 1 - \exp[-V_{si}L/q] \tag{1}$$

where q is the specific discharge and L is the length of the pond (Fig. 1). When the ponded area retains significant transport capacity, trapping efficiency is reduced and a transport capacity or sediment re-entrainment term must be added.[4]

Increased Infiltration of Water into Soil

Vegetation increases infiltration by: 1) reducing the development of surface seals that limit infiltration rates; 2) increasing soil water storage capacity through evapotranspiration; and 3) developing soil macroporosity through root growth and enhanced activities mesofauna such as earthworms and ants. By covering the soil and absorbing the kinetic energy of raindrops, vegetation can prevent the detachment and rearrangement of soil particles that result in the creation of soil seals[5] and thus increases infiltration. Although water use varies with species and climate, vegetation transpires approximately 0.3 m^3 of water for each kg of above-ground dry matter produced.[6] This transpiration leaves more capacity in the soil for infiltration of subsequent rains and thus reduces runoff and erosion.[7] Vegetation increases soil macroporosity directly through root growth[8] and indirectly by improving the habitat and activity of mesofauna.[9] By slowing runoff, vegetation increases the depth of ponded water and the area of soil that that is submerged, thus increasing opportunities for macropore flow.

Encyclopedia of Water Science
DOI: 10.1081/E-EWS 120010092

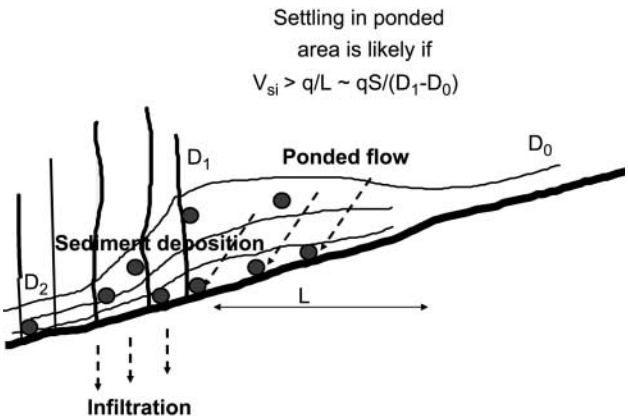

Fig. 1 Schematic illustration of how vegetative buffers slow runoff, increasing flow depth and trapping sediment.

Reduced Soil Erodibility

Soil erodibility refers to the ease with which soil particles (primary or aggregates) can be detached and transported by the shear forces associated with raindrop splash or flowing water. Soil with increased organic matter content has greater aggregate stability,[10] and hence greater resistance to detachment and transport. The effects of vegetation on reducing erodibility include consolidation of soil with time after tillage and binding together of soil particles by roots and by microorganisms that use plant biomass and exudates as a food source.[11]

VEGETATIVE BUFFERS

Buffer Types

Conservation buffers designed to reduce soil erosion and/or sediment delivery are usually areas of perennial vegetation placed at critical points in a landscape. These buffers may be located along stream banks, along the edges of fields, or may be placed within fields. To distinguish among these buffer types, the nomenclature of the U.S. Department of Agriculture—Natural Resources Conservation Service (NRCS) is adopted.

The seven conservation buffers types that reduce sediment delivery in runoff are summarized in Table 1. Practices normally located at the edges of fields are listed first, and those usually placed within fields are listed last. In addition to controlling erosion and/or reducing sediment delivery, many of these buffers can also serve additional purposes such as improving water quality and providing wildlife habitat. Current national standards for these practices are given in the NRCS National Handbook of Conservation Practices, which is available on the internet: http://www.ftw.nrcs.usda.gov/nhcp_2.html. Descriptive information about each practice can be found in the CORE4 training materials: http://www.nhq.nrcs.usda.gov/technical/ECS/agronomy/core4.pdf. Local specifications criteria can be found in the local NRCS Field Office Technical Guide.

The edge-of-field buffers are: Riparian forest buffer (RFB), filter strip (FS), and field border (FB). An RFB is a forested area adjacent to a water body and is frequently combined with grass buffers. A field boarder is a grassed field margin. Because it may be used for parking and turning equipment, a FB is also usually wider than the minimum indicated in Table 1. In contrast to an FB, traffic is usually excluded from an FS and vegetation and slope requirements are far more stringent (Table 1). Generally, edge-of-field buffers are designed primarily to trap sediment and infiltrate water, not to control in-field erosion. The RFB is an exception in that it can control concentrated flow erosion caused by out-of-bank flood flows. The FB controls local scour on sloping head lands where concentrated water flows enter or exit a field. To properly function, these edge-of-field buffers require that runoff pass through them as diffuse, sheet flow.

The other four buffer types in Table 1 function within fields and are designed to control in-field erosion. Three of these buffers, alley cropping (AC), contour buffer strip (CBS), and vegetative barrier (VB) control sheet-and-rill erosion by interrupting hillslopes with strips of permanent vegetation aligned close to the contour (Fig. 2). The widths of these buffers are often varied so that the edges of each cropped zone stay parallel and within strip gradient specifications (Table 1). Alley cropping involves growing crops and forages between strips of trees. Vegetative barriers are usually narrow strips of large stiff-stemmed grasses (Fig. 2). Contour buffer strips are somewhat wider strips with less stringent vegetation and contour alignment requirements (Table 1).

Only two buffer practices, grassed waterway (GW) and VB, may be specifically designed to control in-field concentrated-flow erosion. Grassed waterways are oriented up-and-down the slope and are planted with vegetation that is intended to be submerged while functioning. In contrast, VB designed to controlling concentrated-flow erosion are planted perpendicular to the flow direction and are intended to remain unsubmerged while retarding runoff.

Buffer Hydraulic Resistance

The hydraulic resistance of vegetation frequently is parameterized with Manning's equation:

$$V = \frac{1}{n} R^{2/3} S^{1/2} \tag{2}$$

Marcel Dekker, Inc.
270 Madison Avenue, New York, New York 10016

Table 1 Comparison of water erosion control purposes and selected criteria of buffers types in the USDA-NRCS National Handbook of Conservation Practices that can be used to reduce sediment

		Erosion control purposes		Criteria					
Buffer type	**NRCS code**	**Sheet-and-rill erosion**	**Concentrated flow erosion**	**Field slope (%)**	**Maximum strip gradient**	**Minimum strip width (SW) (m)**	**Strip spacing**	**Maximum field length**	**Minimum stem density**
Riparian forest buffer	391		+		Along stream corridor	11			
Field border	386		+		Along field edge	6			
Filter strip	393			1–10	< 0.5%	6		50 × SW	$1500\,m^{-2}$
Grassed waterway	412		+		Along flow gradient		In concentrated flow areas		n-VR curve and permissible velocity
Alley cropping	311	+			Contour	6	Species light requirements		
Contour buffer strip	332	+		2–8	< 2%	5 (Grass)	1/2 of RUSLE critical slope length (CSL)	RUSLE	$540\,m^{-2}$ (Grass)
						9 (Legume)		CSL	$320\,m^{-2}$ (Legume)
Vegetative barrier	601	+	+		< 1%	1	1.3–2.0 m		Depends on stem diameter (Table)

Source: http://www.ftw.nrcs.usda.gov/nhcp_2.html.

where V is the average flow velocity, R is the hydraulic radius (flow-area divided by wetted perimeter), S is the land slope gradient, and n is a hydraulic resistance parameter. Fig. 3 shows how Manning's n varies with the product V and R for three kinds of buffer vegetation. At low flows with unsubmerged vegetation, the hydraulic radius reduces to the flow depth, H, and VR equals the specific discharge. When the dominant component of hydraulic resistance is drag on emergent stems that are uniform with height, such as with the simulated FSs made of brush bristles (Fig. 3) in a flume with a smooth floor,[13] average velocity remains constant with increasing flow and n increases in proportion to the 2/3 power of discharge.[14]

Fig. 2 Vegetative barriers of vetiver grass (*Vetiveria zizanioides*) planted in rows on contour lines to hold the soil in St. Vincent, British West Indies, during the 1950s.[12]

At high flows, all of the vegetation is submerged and the main factor determining hydraulic resistance is the length of the stems that are dragging in the flow.[15] As discharge increases, more and more of the flow occurs in the zone above the submerged vegetation until eventually the hydraulic resistance of the vegetation becomes a constant. The vegetal retardance curve labeled "A" in Fig. 3 represents 0.9–1.0 m tall vegetation while "E" reflects vegetation that had been burned or mowed at about 4 cm height. In designing a GW, the erodibility of the underlying soil and the growth characteristics of the vegetal cover determine a maximum permissible velocity or the allowable hydraulic stress on the soil, and the channel is designed with dimensions great enough that, with expected vegetation, the permissible velocity or stress will not be exceeded at the design discharge.

Vegetative barriers have application at specific discharges that span the range between those of FS and GW (Fig. 3) and can thus be used to complement other buffer types by spreading out concentrated runoff. At low flows, the hydraulic resistance of VB increases more rapidly than the 2/3 power of discharge because stems and leaves become less clumped together, increasing projected area with increasing height in the lower canopy. At greater discharges, flow-depth increases to the point where stems begin to thin out or bend. Then average velocity increases, the flow resistance, expressed as Manning's n, ceases to increase and begins to decline, even while flow depth may continue to increase with increasing discharge.[16] The stiff grasses used to form VB remain erect and emergent at greater flows than other vegetation types in Fig. 3 because the large-diameter stems are stiffer and are on the order of 2 m tall. The enhanced growth and residue loading noted to occur at the edge of all buffers are also important factors

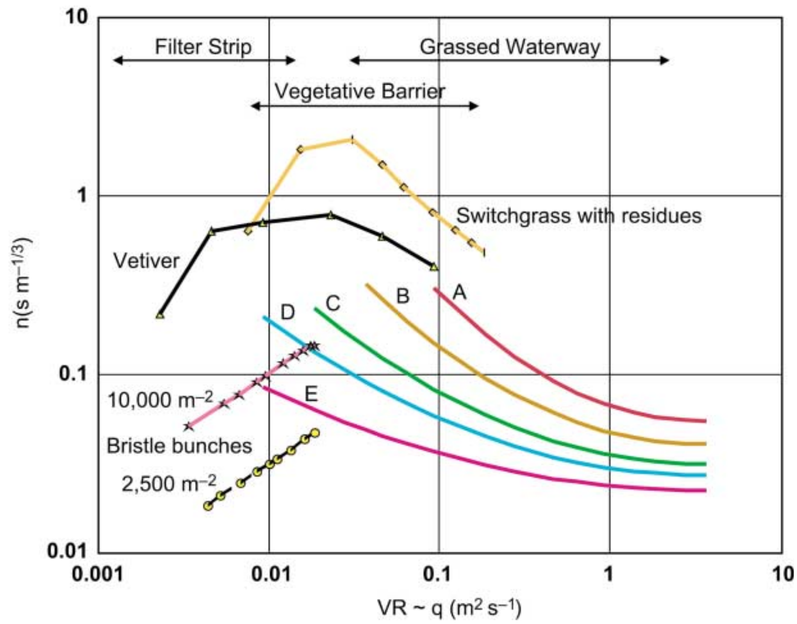

Fig. 3 Hydraulic roughness of vegetated areas first increases with increasing flow as more vegetation interacts with the flow, then decreases with increasing flow as flow approaches the height of the vegetation and submerges it. Data for A–E from Ref. [15]; brush bristle data from Ref. [13]; switchgrass (*Panicum virgatum*) data from Ref. [16]; vetiver from Dabney (unpublished).

that give VB greater hydraulic resistance than retardance class A vegetation. Riparian forest buffer vegetation, of course, remains erect at even greater flows than does VB vegetation, but usually offers less hydraulic resistance at low flows.

REFERENCES

1. Parsons, D.A. *Depths of Overland Flow*, SCS-TP-82; U.S. Dept. of Agriculture-Soil Conservation Service: Washington, DC, 1949; 1–33.
2. Meyer, L.D.; Wischmeier, W.H. Mathematical Simulation of the Process of Soil Erosion by Water. Trans. ASAE **1969**, *12* (754–758), 762.
3. Dabney, S.M.; Meyer, L.D.; Harmon, W.C.; Alonso, C.V.; Foster, G.R. Depositional Patterns of Sediment Trapped by Grass Hedges. Trans. ASAE **1995**, *38* (6), 1719–1729.
4. Beuselinck, L.; Govers, G.; Steegen, A.; Harisine, P.B.; Poesen, J. Evaluation of the Simple Settling Theory for Predicting Sediment Deposition by Overland Flow. Earth Surf. Process. Landforms **1999**, *24*, 993–1007.
5. Römkens, M.J.M.; Prasad, S.N.; Whisler, F.D. Surface Sealing and Infiltration. In *Process Studies in Hillslope Hydrology*; Anderson, M.G., Burt, T.P., Eds.; John Wiley & Sons, Ltd.: New York, 1990; 127–172.
6. Tanner, C.B.; Sinclair, T.R. Efficient Water Use in Crop Production: Research or Re-search. In *Limitations to Efficient Water Use in Crop Production*; Taylor, H.M., Ed.; Am. Soc. Agron.: Madison, WI, 1983; 1–27.
7. Zhu, J.C.; Gantzer, C.J.; Anderson, S.H.; Alberts, E.E.; Beuselinck, P.R. Runoff, Soil and Dissolved Nutrient Losses from No-Till Soybean with Winter Cover Crops. Soil Sci. Soc. Am. J. **1989**, *53*, 1210–1214.
8. Tomlin, A.D.; Shipitalo, M.J.; Edwards, W.M.; Protz, R. Earthworms and Their Influence on Soil Structure and Infiltration. *Earthworm Ecology and Biogeography in North America*; Lewis Pub.: Boca Raton, FL, 1995; 159–183.
9. Elkins, C.B.; Harland, R.L.; Homeland, C.S. Grass Roots as a Tool for Penetrating Soil Hardpans and Increasing Crop Yields. Proc. South. Pasture Forage Crop Imp. Conf. **1977**, *34*, 21–26.
10. Angers, D.A. Changes in Soil Aggregation and Organic Carbon Under Corn and Alfalfa. Soil Sci. Soc. Am. J. **1992**, *56*, 1244–1249.
11. Renard, K.G.; Foster, G.R.; Weesies, G.A.; McCool, D.K.; Yoder, D.C.; (coordinators) *Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE)*, Agric. Handbook 703; U.S. Department of Agriculture-Agricultural Research Service: Washington, DC, 1997; 1–384.
12. Vélez, I. Soil Conservation Practices in the Caribbean Archipelago. Sci. Monthly **1952**, *74* (3), 183–185.
13. Jin, C.X.; Römkens, M.J.M.; Griffioen, F. Estimating Manning's Roughness Coefficient for Shallow Overland Flow in Non-submerged Vegetative Filter Strips. Trans. ASAE **2000**, *43* (6), 1459–1466.
14. Petryk, S.; Bosmajian, G. Analysis of Flow Through Vegetation. J. Hydr. Div. ASCE **1975**, *101* (HY7), 871–884.

15. Temple, D.M.; Robinson, K.M.; Ahring, R.M.; Davis, A.G. *Stability Design of Grass-Lined Open Channels*, Agric. Handbook 667; U.S. Department of Agriculture-Agricultural Research Service: Washington, DC, 1987.
16. Temple, D.; Dabney, S. *Hydraulic Performance Testing of Stiff Grass Hedges*, Proceedings of the Seventh Federal Interagency Sedimentation Conference, Reno, Nevada, 25–29 March, 2001; Vol. 2 (XI), 118–124.